The Shuttle Radar Topography Mission: A Global DEM

Tom G. Farr, Mike Kobrick
Jet Propulsion Laboratory
California Institute of Technology
Pasadena, CA USA

Digital topographic data are critical for a variety of civilian, commercial, and military applications. Scientists use **Digital Elevation Models (DEM)** to map drainage patterns and ecosystems, and to monitor land surface changes over time. The mountain-building effects of tectonics and the climatic effects of erosion can also be modeled with DEMs. The data's military applications include mission planning and rehearsal, modeling and simulation. Commercial applications include determining locations for cellular phone towers, enhanced ground proximity warning systems for aircraft, and improved maps for backpackers.

The **Shuttle Radar Topography** Mission (SRTM) (Fig. 1), is a cooperative project between the National Aeronautics and Space Administration (NASA) and the National Imagery and Mapping Agency (NIMA) of the U.S. Department of Defense. The mission is designed to use a single-pass radar interferometer to produce a digital elevation model of the Earth's land surface between about 60° north and 56° south latitude. The DEM will have 30 m pixel spacing and approximately 15 m vertical errors.
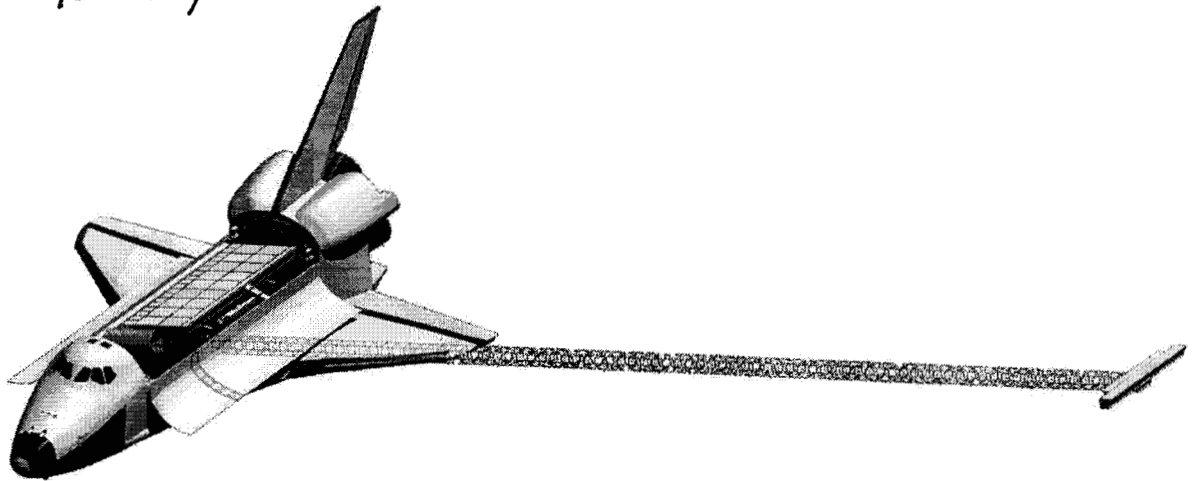
interferometry

Figure 1. The SRTM payload in the Space Shuttle. The main antenna is seen in the payload bay and the outboard antennas are at the end of a 60 m mast.

The technique to acquire this data set has been used for over a decade to produce accurate topographic and topographic change maps (Zebker and Goldstein, 1986; Evans et al., 1992; Madsen et al., 1993; Gens and Vangenderen, 1996; Massonnet, 1997; Zebker and Madsen, 1998). Radar interferometry uses

the fact that the sensor is phase-coherent, so that if two images are acquired at two slightly different locations, a phase-difference image can be produced that contains information on the topography. The two images can be obtained simultaneously, as with most airborne systems, or at different times, which is the case with all current single-aperture spaceborne systems. The main drawbacks to the repeat-pass mode is the need to know the baseline separation of the two images to the mm level, and changes in the atmosphere and surface can occur between the two passes.

The repeat-pass baseline can be determined by obtaining a few ground control points (Zebker et al., 1994), however the other effects are much more difficult to alleviate. Water vapor in the troposphere adds a significant phase delay, which, if different at the two times of image acquisition, will cause large errors in the topographic map produced (Goldstein, 1995; Massonnet and Feigl, 1995; Tarayre and Massonnet, 1996; Zebker et al., 1997). This effect has been noted by many investigators; the only feasible way to counteract it is to acquire many pairs of images and search for the best pairs. Surface changes that degrade the interferometric measurement include incoherent sub-pixel motion such as the waving of leaves and branches on trees (Zebker and Villasenor, 1992). This decreases the amount of correlation between the two images, increasing the error of the phase measurement. In extreme cases, complete decorrelation results in loss of the phase information.

To avoid the problems with repeat-pass interferometry, SRTM will acquire its two images simultaneously. SRTM will use the same radar instrument that comprised the Spaceborne Imaging Radar-C/X-band Synthetic Aperture Radar (SIR-C/X-SAR) that flew twice on the Shuttle Endeavour in 1994 (Stofan et al., 1995; Lanari et al., 1996; Moreira et al., 1995). To collect the interferometric data, a 60 m mast, additional C-band antenna, and improved tracking and navigation devices will be added. A second X-band antenna is also planned to be added by the German Aerospace Center (DLR), which will produce higher resolution topographic measurements in strips nested within the full, C-band coverage (DLR, 1998).

The major part of the SRTM hardware will reside in the payload bay of the Space Shuttle (Fig. 2). This will include the main structure, supporting the L, C and X-band antennas, the mast canister, and the Attitude and Orbit Determination Avionics. During nominal SRTM operations, the L-band system will not be used; the C-band system will be operated in a scanSAR mode to acquire a 225 km swath, allowing complete coverage with a small overlap at the equator. Owing to the nature of the original SIR-C/X-SAR digital data handling system, the scanSAR system will operate in a dual-polarization mode: two beams will be HH polarization and two will be VV.
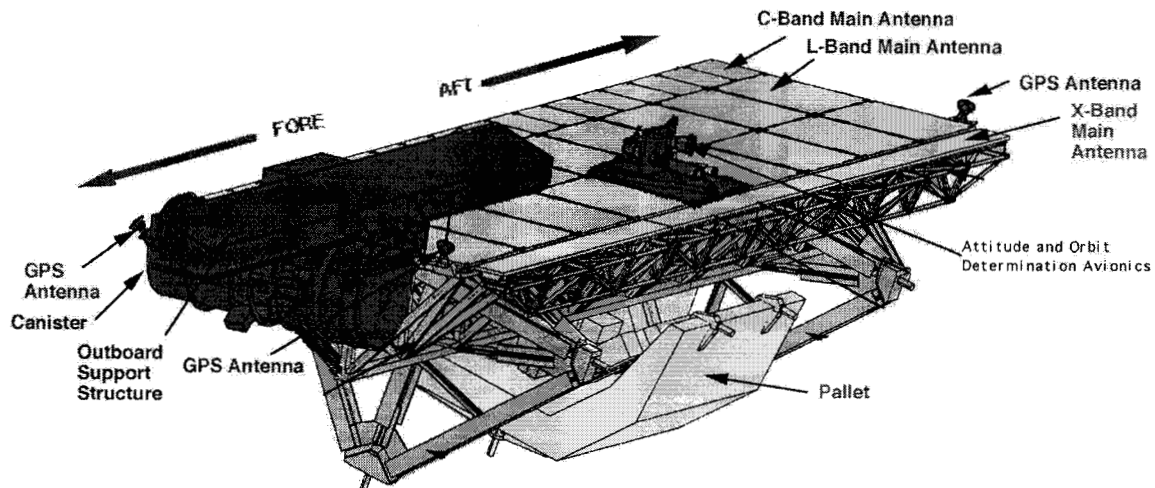
Figure 2. A detailed view of the SRTM hardware in the Space Shuttle payload bay. The 60 m mast is in its stowed configuration; the outboard antennas are folded back on top of the canister.

The 60 m mast was produced by AEC-Able Engineering, Inc., based on designs for the International Space Station. It consists of carbon-fiber longerons forming cubes, or bays, with titanium wires under tension as cross-braces. There are 87 bays, each about 70x80 cm making up the full 60 m length. The mast is stored as a collapsed spiral in a canister 2.9 m in length. When deployed, the Shuttle with the mast will be the largest structure ever flown in space.

An important addition to the original SIR-C/X-SAR hardware is the Attitude and Orbit Determination Avionics (AODA). This system is required to obtain data on the length and orientation of the mast and the location and orientation of the Shuttle in earth-centered inertial coordinates (Duren et al., 1998). These factors are critical to the creation of an accurate digital topographic map automatically without the necessity of ground control points. AODA occupies the place of one of the L-band panels on the face of the main antenna (Fig. 2). It consists of an Astro Target Tracker, Electronic Distance Meter, Star Tracker, GPS receiver, and Inertial Reference Unit. The Astro Target Tracker will track a set of LEDs mounted on the outboard antenna structure, recording data on the motions of the outboard antenna relative to the main antenna. The Electronic Distance Meter will measure the length of the mast to better than 3 mm. The Star Tracker will identify and track stars passing through its field of view, providing a highly accurate position for the Shuttle. The GPS receiver will handle signals from antennas on both the outboard and main antennas (Duncan et al., 1998). AODA data will be stored on the Shuttle as well as sent to the ground for incorporation into the processing stream of the interferometric data.

Another important addition to the SRTM hardware is the presence of several laptop computers in the mid-deck of the Shuttle. These will perform 2

functions: Monitor and archive AODA data, and control the Payload High Rate Recorders. AODA data will be sent to one set of laptops so that the Shuttle crew can monitor mast motions. This will also aid in the initial alignment of the two antennas. The recorders are the same as flew on the SIR-C/X-SAR missions, but due to a desire to more efficiently pack data onto a limited number of tapes and the fact that some data takes will be longer than a single tape, a more sophisticated controller was needed. The laptops controlling the recorders will sense the approaching end of a tape, start the next recorder to produce overlapped data, and then hand over to the second recorder.

The SRTM flight is currently scheduled for September 1999; flight hardware is being integrated at JPL and will be delivered to Cape Canaveral for Shuttle integration in early 1999. The flight is planned for 11 days at 233 km and 57 degrees inclination, which gives a 10 day exact repeat period. Upon landing, the data tapes will be transferred to JPL for copying and distribution to the processing center. After a checkout and calibration period of a few months, full data processing will take approximately 1 year. The strip data will be compiled into mosaics on a continent basis, allowing block adjustments on that scale. Mosaics will be delivered to NIMA, where validation of the data set will be done. NIMA will deliver data to the civilian archive at the US Geological Survey's EROS Data Center.

An extensive program for calibration and verification of the SRTM data will be undertaken. The calibration of the interferometer will allow fully automatic processing of the data to calibrated DEMs. In addition to the measurements made by AODA, radar path delays will be monitored by a phase-locked optically coupled calibration tone injected at the input to the receiver chains. These systems provide accurate relative calibration over short (less than the orbit period) time scales. Absolute calibration will be carried out through measurements at two ground control sites as well as of the ocean surface before and after every coast crossing, along with a few long deep-ocean passes.

Verification of the interferometric data and the DEMs will be accomplished through the use of 3 major test sites containing high-resolution DEMs and ground control points, some of which will be recognizable in the image data. In addition, a globally distributed set of small, high-resolution DEMs, ground control points, and kinematic GPS surveys will be used in order to evaluate long period errors in the final DEM mosaics.

More information about the Shuttle Radar Topography Mission can be found at the NASA/JPL Radar Program Web site: http://southport.jpl.nasa.gov.

* Work performed under contract to NASA and NIMA.

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